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MINIATURIZED SIZE BRANCH LINE COUPLER USING OPEN STUBS WITH HIGH-LOW IMPEDANCES

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Abstract—In this paper, a miniaturized branch-line coupler is proposed. The topology of the circuit is designed using novel design of T-model approach with open stubs with high-low impedances, which provides necessary bandwidth for WLAN band at 2.45 GHz. The miniaturized branch-line coupler is designed and fabricated with a low-cost FR4 substrate as a platform in producing significantly reduction by more than 64.21% compared to the conventional coupler on inexpensive board. Furthermore, the coupler can equally divide the input signal with 90° phase of difference while maintaining the initial power from the source.

1. INTRODUCTION

The branch-line coupler can be used as a power divider, combiner or a part of mixer in microwave integrated circuits [1]. In fact, branch-line couplers are widely implemented using stripline [2], multilayer structures [3], microstrip [4], and finite-ground coplanar waveguide [5]. The coupler employs a quarter-wave length transformers to develop a simple square-shaped configuration that is used for power dividing or power combining functions. However, at the lower frequency, the size of conventional branch line is exceedingly large in printed circuit.

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Its physical size is relatively determined by the wavelength which is large at lower frequency, and invariably affects the dimension of quarter-wavelength ($\lambda/4$) transmission lines used. However, nowadays, portable devices require components with compact size and less cost features. Therefore, high performances, compact size and low cost are often the stringent requirements that should be driven forward in order to fulfil the demand of modern microwave communication systems [6]. Hence, the reduction of the size of the transmission lines is crucial and will invariable help to shrink the size of the coupler.

To shrink the size of the coupler, there are several techniques which have been proposed and developed [7–18]. The lumped-element technique described in [7, 8] provides significant size reduction. However, the design of lumped-element circuits must be rather pragmatic and needs precise inductor models based on careful measurements of test elements [9]. The combination of shunt lumped capacitors with short high-impedance transmission lines is another option in shrinking the coupler's size [10–12]. Unfortunately, the usage of metal-insulator-metal (MIM) capacitors used to implement this method inflates the cost and complexity of fabrication, indirectly. Additionally, Ring and Line Rat-race hybrid couplers as an alternative to produce compact designs have been proposed in [13–15]. Besides that, the design method proposed in [16] by using fractal-shaped branch-line coupler can reduce the size about 81.8% but along with the disadvantage that the operating frequency and bandwidth are unaltered. In [17], a 60% reduction in size of the coupler is achieved using discontinuous microstrip lines by having the design fabricated in costly board.

In this paper, a method of open stubs with low and high impedances is introduced and applicable to shrink the length of the transmission line and invariably the dimension of the branch line coupler. This paper is closely related to the concept design of T-model and π model as introduced in [17, 18], respectively. Hence, the proposed novel technique which combines high and low impedance in order to miniature size achieves greater reduction of 64.21% compared to conventional ones. The proposed design also considers the performance of the prototype in terms of equal division of the input signal while maintaining the initial power from the source.

2. COUPLER STRUCTURE

Traditionally, due to their symmetry the normal-mode analysis, even-mode analysis and odd-mode analysis are often used in the design of the branch-line coupler. The equivalent circuit of the quarter-wavelength

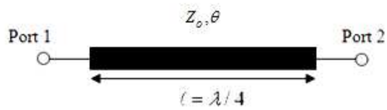


Figure 1. Equivalent circuit of the quarter-wavelength transmission line.

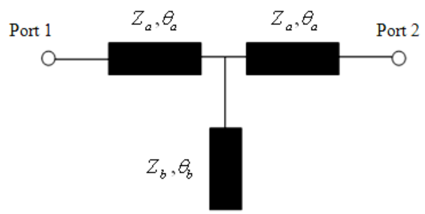


Figure 2. Equivalent quarter-wavelength transmission line of T-model.

transmission line is shown in Figure 1.

The terms Z_o and θ are the characteristic impedance and electrical length of conventional branch line arms of coupler, respectively. In order to shorten the quarter-wavelength transmission line, equivalent T-model of the transmission line is employed as illustrated in Figure 2. T-model approach is adopted individually in the effort of shortening quarter-wavelength transmission lines thus miniaturized the microstrip branch-line couplers. Defining the sets $Z_o \equiv [Z_a, Z_b]$ and $\theta \equiv [\theta_a, \theta_b]$, the equivalent T-model is shown in Figure 2.

In order to relate the models in Figures 1 and 2, we resort the ABCD matrices equation given by:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\lambda/4} = \begin{bmatrix} 0 & jZ_o \\ jY_o & 0 \end{bmatrix} \tag{1}$$

where $A = D = 1 + Z_a/Z_b$, $B = Z_a(2 + Z_a/Z_b)$ and $C = 1/Z_b$. The set $[\theta_a, \theta_b]$ are the electrical lengths of the reduced line.

By using the expression for the T-model in [17], we can express the design equations for the miniaturized branch-line coupler of reduced quarter-wavelength line as been shown in Equation (2)–Equation (3).

$$Z_a = \frac{Z_o}{\tan\theta_a} \tag{2}$$

$$Y_b \tan\theta_b = \frac{2}{Z_a \tan 2\theta_a} \tag{3}$$

where $\theta = \beta\ell$ and $\beta = 2\pi/\lambda$

The design of a high-impedance transmission line based on T-model quarter-wavelength transmission line is shown in Figure 3. The length of fabricated shunt line of branch-line coupler is 10 mm, which offers about 41.1% reduction from the conventional shunt arm line of conventional coupler.

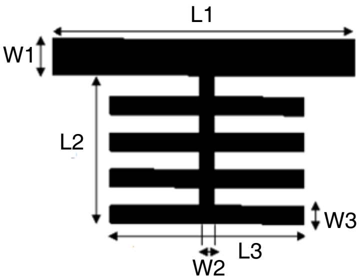


Figure 3. T-Model with high-impedance approach.

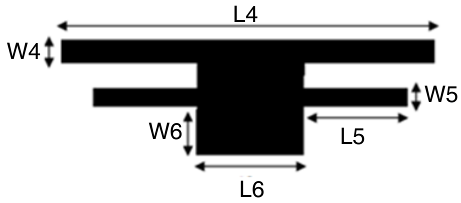


Figure 4. T-Model with low-impedance approach.

Table 1. Dimensions of the proposed miniature size coupler design.

Dimension of new design	Impedance (Ω)	Electrical length ($^\circ$)	Width (mm)	Length (mm)
(W_1, L_1)	11.81	6.06	1	10
(W_2, L_2)	89.64	21.42	0.4	4.1
(W_3, L_3)	19.74	2.95	0.5	5.4
(W_4, L_4)	76.62	69.92	0.6	13.2
(W_5, L_5)	82.48	18.42	0.5	3.5
(W_6, L_6)	26.98	15.00	3.6	2.6

The layout of a branch line with a low-impedance T-model quarter-wavelength branch line is depicted in Figure 4. In this case, a 26.26% reduction in through line size of branch line coupler is achieved when the length of fabricated branch line is measured at 16 mm.

The dimensions of the open stub high and low transmission lines are derived using the electromagnetic simulator AWR Tool Calculator based on the impedance and electrical length of each transmission line. The physical design parameters are labeled as L_1–L_6, and W_1–W_6 have been derived automatically using the electromagnetic simulator with the impedance and electrical length of every transmission line in the design. Both side of through and shunt arm of the couplers were built on FR-4 substrate with permittivity, permeability, loss tangent and heights are 4.7, 1, 0.019 and 0.8 mm, respectively.

Table 1 tabulates the overall dimensions of the coupler based on the calculation earlier. This study follows with Figure 5 which shows the schematic layout of the miniaturized design. The low-impedance and high-impedance structures are dually located at the top-bottom and left-right positions, respectively. Figure 6 illustrates

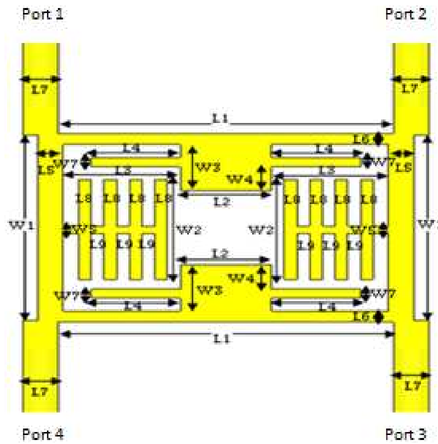


Figure 5. Dimensions of the proposed structure.

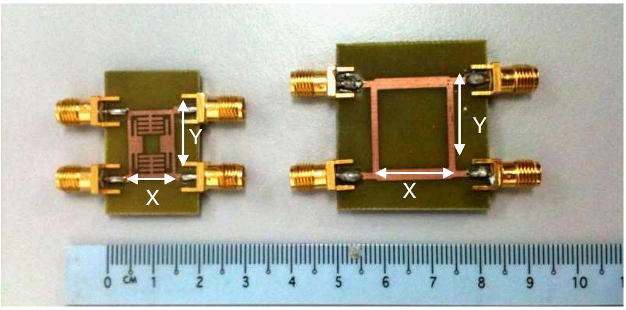
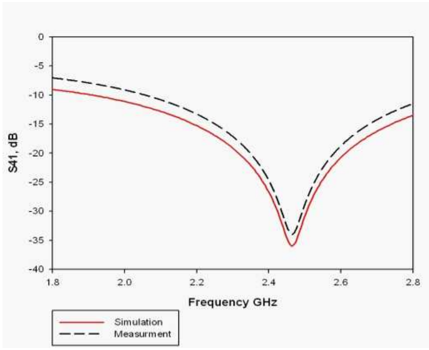


Figure 6. Size comparison of new (left) and conventional branch line (right) couplers.

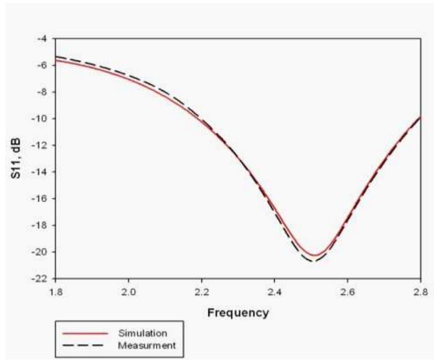
the miniature coupler and conventional coupler for comparison. The dimension of fabricated coupler is 13.2 mm × 10 mm and the area of the conventional coupler is 368.9 mm^2 versus 160 mm^2 for the miniaturized ones, about 64.21% smaller. Both couplers were built on inexpensive FR-4 substrate with permittivity, permeability; loss tangent and height are 4.7, 1, 0.019 and 0.8 mm, respectively.

3. RESULT AND ANALYSIS

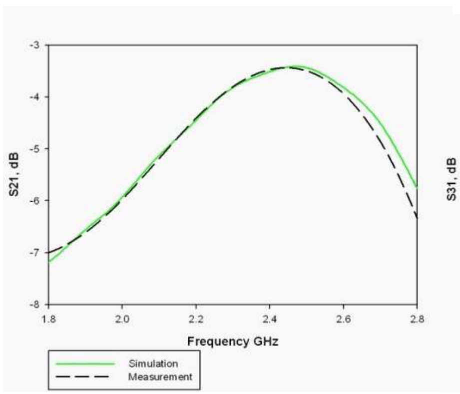
The measured and EM simulated response of the microstrip branch-line coupler using open stub with high and low impedance wavelength transmission line with the T-model are demonstrated in Figure 7.



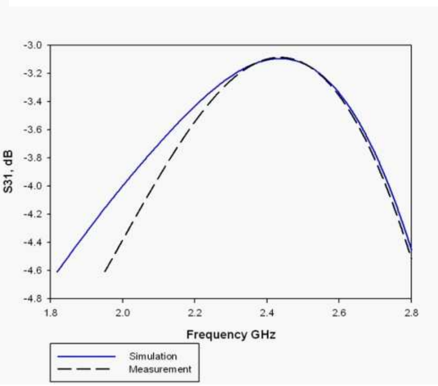
(a)



(b)



(c)



(d)

Figure 7. Simulation and Measurement results: (a) magnitude of $|S_{41}|$, (b) magnitude of $|S_{11}|$, (c) magnitude of $|S_{21}|$, (d) magnitude of $|S_{31}|$.

The coupler's S-parameter is analyzed at the operating frequency of 2.45 GHz. The isolation factor versus frequency is shown in Figure 7(a) at a frequency band from 1.8 GHz to 2.8 GHz. It is observed that the isolation factor gets as high as -36.2 dB at the center frequency of 2.45 GHz.

Symmetry structures and reciprocity characteristics contribute to the same value of coupler's S_{11} (return loss) reflection coefficient. The reflection factor is equal to -21.7 dB at the frequency band from 2.1 GHz up to 2.8 GHz with the centre frequency of 2.45 GHz as shown in Figure 7(b).

The coupling factors S_{21} and S_{31} approaching ideal value, -3 dB, which determines the coupler's ability to divide the input signal equally

Table 2. Performance of miniaturized branch-line coupler.

Parameters	**Conventional**	**Miniaturized Size**
Frequency	2.45 GHz	
S_{11}	−32.058 dB	−21.7 dB
S_{21}	−2.664 dB	−3.2 dB
S_{31}	−3.355 dB	−3.1 dB
S_{41}	−36.519 dB	−36.2 dB
Phase difference	89.9°	89°
Size Y × X mm^2	21.7 mm × 17 mm ($368.90\,mm^2$)	13.2 mm × 10 mm ($160\,mm^2$)
Percentage of Reduction	64.21%	

at the output port. The magnitudes of the coupling factors at the preferred bandwidths are shown in Figure 7(c) and Figure 7(d). The magnitude of the coupling factor is −3.5 dB at the center frequency of 2.45 GHz and approximately constant at the desired frequency range.

Table 2 tabulates dimensional comparison between the miniaturized coupler and the conventional one. This geometry offers an obvious 64.21% reduction in size of the branch-line coupler compared to the conventional branch-line. The range of bandwidth covered is from 2.1 GHz to 2.8 GHz. Meanwhile, the amplitude and phase differences between parameters S_{21} and S_{31} are within ±0.1 dB and 90° ± 5°, respectively.

Miniaturization is one of the most important issues that should be considered while designing a coupler. As stated earlier in the introduction, conventional branch-line coupler has a bulky dimension at a lower frequency. Referring to the bandwidth calculation from Equation (4), the −10 dB bandwidth of conventional design yield of 23.02% cover from 2.13 GHz to 2.68 GHz compared to the miniaturized size branch-line coupler, 22.08% of bandwidth percentage cover frequencies 2.23 GHz to 2.78 GHz. It illustrates that only slight percentage difference between the conventional and miniaturized size design as been listed in Table 3.

$$\text{Bandwidth (BW)} = \frac{f_2 - f_1}{\sqrt{f_2 \cdot f_1}} \times 100\% \tag{4}$$

Dividing power equally and obtaining an accurate phase difference is extremely important in the coupler design. The difference between S_{21} and S_{31} is 0.1 dB at 2.45 GHz frequency. There is only a slightly changes at this frequency bandwidth. Therefore, it apparently indicates that the proposed coupler can exactly divide the input signals

Table 3. Conventional vs. miniaturized branch line coupler.

Parameter	Conventional	Miniaturized
Length (mm)	21.7 mm	13.2 mm
Width (mm)	17 mm	10 mm
Percentage Bandwidth (%)	23.02	22.08

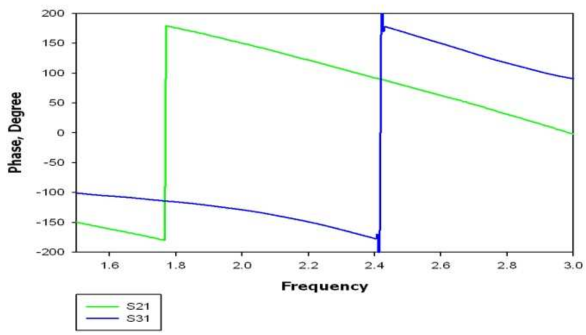


Figure 8. Phase difference between Ports 2 and 3.

equally because the value is roughly constant at the bandwidth of the local oscillator.

The phase difference between the coupler's output ports is depicted in Figure 8. The phase difference is 89° at 2.45 GHz. Such value is acceptable for all receivers since ±5° error is negligible and indicates good transmission percentage.

The phase difference of the coupler is as good as the conventional one but its performance is significantly better in terms of power dividing. Furthermore, the size of the proposed coupler is very small compared to the conventional coupler. This miniaturized prototype coupler is suitable for Wireless Local Area Network (WLAN) application at the frequency of 2.45 GHz.

4. CONCLUSION

Recently, miniaturization microwave circuit has been the main target of many researchers to reduce cost. In this paper, the conventional branch line coupler and the proposed miniaturized one were designed, simulated and fabricated at the frequency of 2.45 GHz. By implementing CST studio software, both couplers were etched on the same FR4 substrate. The size reduction of the proposed design is 64.21% with comparable performance as that of the conventional branch line coupler. The ease of design using standard etching process makes the fabrication of the miniaturized coupler simpler and with low cost. This prototype can be integrated into the design of microwave or millimeter-wave integrated circuits where the compactness of components is crucial.

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